EXHIBIT 38

Forced-Air Warming Design: Evaluation of Intake Filtration, Internal Microbial Buildup, and Airborne-Contamination Emissions

Mike Reed, MBBS, MD, FRCS
Oliver Kimberger, MD
Paul D. McGovern, BSc, MBBS, MRCS, PGCME, FHEA
Mark C. Albrecht, MStat, MBA, BSME

Forced-air warming devices are effective for the prevention of surgical hypothermia. However, these devices intake nonsterile floor-level air, and it is unknown whether they have adequate filtration measures to prevent the internal buildup or emission of microbial contaminants.

We rated the intake filtration efficiency of a popular current-generation forced-air warming device (Bair Hugger model 750, Arizant Healthcare) using a monodisperse sodium chloride aerosol in the laboratory. We further sampled 23 forced-air warming devices (same model) in daily hospital use for internal microbial buildup and airborne-contamination emissions via swabbing and particle counting. Laboratory testing found the intake filter to be 63.8% efficient. Swabbing detected microorganisms within 100% of the forced-air warming blowers sampled, with isolates of coagulase-negative staphylococci, mold, and micrococci identified. Particle counting showed 96% of forced-air warming blowers to be emitting significant levels of internally generated airborne contaminants out of the hose end. These findings highlight the need for upgraded intake filtration, preferably high-efficiency particulate air filtration (99.97% efficient), on current-generation forced-air warming devices to reduce contamination buildup and emission risks.

Keywords: Airborne contamination, filtration, forced-air warming, operating room ventilation, patient warming.

Forced-air warming (FAW) is widely used to prevent surgical hypothermia. The benefits of preventing surgical hypothermia include reduced blood loss, improved wound healing, reduced duration of hospital stay, improved survival, and reduced rates of surgical site infections.[1] Ideally, the air exhaust from FAW devices should be free of particulate matter and microorganisms since the airflow is often vented near the operative site. To reduce contamination emission risks, FAW devices are equipped with an intake filter, but there is minimal published evidence supporting the performance of the intake filter in regard to (1) protecting the blower's internal air path from a buildup of microbial contamination and (2) preventing the emission of resident airborne contaminants that are drawn into the blower.

Forced-air warming devices employ a 0.2 µm–rated intake filter to prevent the passage of airborne contamination, which consists of all particulate matter suspended in operating theater air. Common forms include microbial-laden dust, desquamated skin, and respiratory droplets.[2] However, the "0.2-µm" rating conveys no information about the quality of the intake filter and instead describes the size of particle with which the filter was challenged. The critical performance parameter is the "filtration efficiency" (ie, how well the filter captures the 0.2-µm challenge particles). Prior research has rated the intake filtration efficiency of legacy FAW devices (Bair Hugger 505, Arizant Healthcare) at 93.8% for an "older" filter model in clinical use (200708C) and 61.3% for a "newer" filter model (200708D) scheduled to replace the older filter in clinical use.[3] This same research found high levels of internal microbial buildup and contamination emissions from these legacy devices in hospital operating theaters using the "older" 93.8% efficient intake filter.

Relatively little is known about the design of current-generation FAW devices regarding intake filtration efficiency. Therefore, in this study we chose to evaluate the filtration performance of a popular current-generation FAW device (Bair Hugger 750) and sample for contamination emissions and/or internal microbial buildup in a European hospital environment.

Methods

Sampling Procedures and Assessments. Sampling procedures included intake filter efficiency, intake filter performance in the operating theater, generation of airborne contamination by the FAW devices, and microbial colonization of the internal air path surface.

Intake Filter Efficiency. New intake filters were ac-

quired from the manufacturer (Arizant Healthcare) for testing filter efficiency, which was measured by challenging the filters with sodium chloride particulate through a range of monodisperse particle sizes (0.025 to 0.50 µm) at an airflow of 45 cu ft/min. The test schematic used the following: an air supply blower; high-efficiency particulate air (HEPA) filtration at the intake; an atomizer (Quant Technologies LLC); an aerosol neutralizer (model 3077, TSI Inc); an electronic classifier (model 3080, TSI Inc); 2 condensation particle counters (models 3772 and 3782, TSI Inc); and an air velocity meter (Dwyer Instruments Inc).

Filtration efficiency was calculated as the fraction of particles captured by the filter during a 10-minute challenge. Challenge concentrations varied from 85,000 to 1,100,000 particles per cubic foot depending on particle size. The most penetrating particle size (MPPS) is defined as the particle size at which the filter displayed a minimum efficiency.

Intake Filter Performance in the Operating Theater. Twenty-three FAW blowers, in a single hospital in Vienna, Austria, were sampled after-hours in the operating theaters to quantify the performance of the intake filter in the clinical environment. This was measured separately from the FAW blower, using a fixture that challenged the intake filter with ambient air in the operating theater. The fixture consisted of a downstream vacuum (calibrated to draw 1,274 L/min or 45 cu ft/min), a mounting plate, and an internal particle sampling pitot tube downstream of the filter. With the intake filter attached to the fixture and the vacuum running, laser particle counts of a 0.1-cu ft sample volume (Particle Measuring Systems) were taken upstream and downstream of the intake filter. Three samples were taken at each location.

Intake filter performance in the operating theater environment was assessed as the fraction of particles 0.3 to 0.5 µm, 0.5 to 5.0 µm, and greater than 5.0 µm captured by the intake filter.

Generation of Airborne Contamination. The filters were replaced, and these same 23 FAW blowers were sampled for generation of airborne contamination, which was determined by comparing observed particle counts in the airstream exiting the FAW blower with what would be predicted based on the measured filtration efficiency of each intake filter. Specifically, we measured particle counts greater than 0.3 µm in the intake and distal airstreams (3 0.1-cu ft samples each).

Afterward, filter particle concentrations were calculated for each FAW blower by (1) computing the average particle concentration greater than 0.3 µm in the intake airstream and (2) multiplying the average intake airstream particle concentration by the fraction of particles greater than 0.3 µm removed by the intake filter (as observed during intake filter performance testing). FAW internal contamination generation was identified by comparing distal airstream particle concentrations with after-filter particle concentrations, which should be the same in the absence of contamination generation.

Internal Air Path Microbial Colonization. For these same 23 FAW blowers, microbial colonization of the internal air path surface was assessed via swabbing. A 10-cm^2 area inside (1) the "distal hose" end and (2) inside the FAW blower directly upstream of the hose connection ("elbow") were sampled. Control swabs were also taken and sent to the microbiology laboratory in a blinded fashion with the active samples. Microbiological culturing and analysis were performed by the in-hospital laboratory.

Colony-forming units (CFU) per swab were assessed by the following process. Swabs were transported to the laboratory in 5 mL of diluent and vortexed in the transport container. One mL of diluent was pipetted in duplicate into Petri dishes, and 25 mL of molten 45°C tryptic soy agar was added to form a nonselective growth medium. The dishes were incubated for 48 to 72 hours at 36.0 ± 0.1°C. Each individual colony was enumerated as a single CFU, and reported values per swab represent the average of the 2 dishes. The CFUs for the locations of distal hose and elbow were those detected from a single swab used at each location. Combined CFUs per FAW blower were the sum of both locations.

The presence of specific microorganisms was also assessed for each FAW blower by pooling the remaining diluent from both locations. This diluent was enriched, incubated (for 24 hours at 36.0 ± 0.1°C), and then tested for the following: mold and *micrococci* using Gram staining; *Staphylococcus aureus* and coagulase-negative *staphylococci* (CoNS) using Gram staining and catalase identification; and methicillin-resistant *S aureus* (MRSA) using oxacillin for test sensitivity.

Statistical Analysis. Forced-air warming blowers having significant internal contamination generation were identified using a variance weighted analysis of covariance (ANCOVA) model, with the difference between distal and after-filter particle concentrations as the response. Predictors included intake particle concentration as a covariate; and blower serial number and treatment (filter isolated or filter on FAW blower) as fixed effects. Significant differences were identified as those having *P* values less than .05 (2-tailed) after Bonferroni correction for familywise error rates (n = 23 comparisons). Given that this was an observational study, sample sizes were not determined a priori.

Pearson correlation coefficients were calculated to assess the linear correlation between FAW blower contamination generation (difference between distal and after- filter particle concentrations) and CFUs detected at each swabbing location. *P* values represent the 2-tailed probability that the Pearson correlation coefficient is equal to zero.

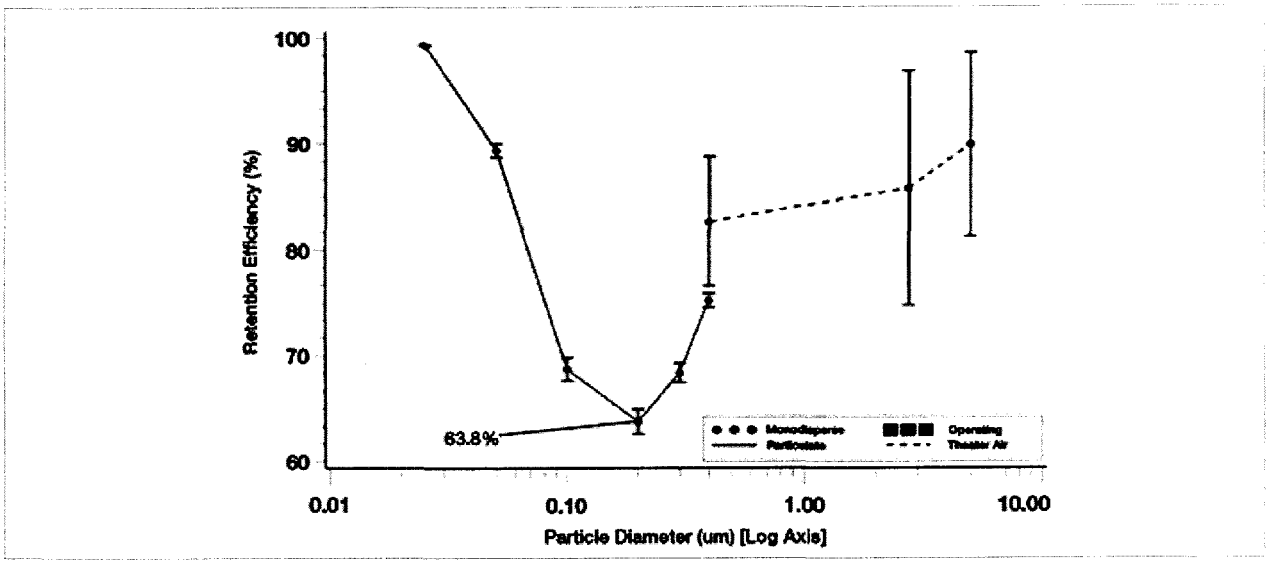

Figure 1. Mean Retention Efficiencies (± standard error of mean) for Intake Filter When Challenged With Operating Theater Air (n = 23) and Monodisperse Sodium Chloride Particulate (n = 5)[a]

[a] Solid line indicates monodisperse sodium chloride particulate; broken line, operating theater air. Disparities in retention efficiency between the 2 test methods at similar particle sizes (in micrometers) arise from differences in both the type of challenge particulate used and particle size classification methods. Intake filter was model 750093D (Arizant Healthcare).

Results

Intake Filter Retention Efficiency. The mean efficiency for intake filter model 750093D (n = 5) was found to be 63.8% at the MPPS of 0.2 µm (Figure 1) using a test method in accordance with ventilation industry standards.

Intake Filter Performance. To confirm that the intake filter was performing within specification in its environment of use, intake filters (model 750093D) from 23 FAW blowers were removed and challenged with operating theater air. Efficiencies for these filters in the operating theater were added to the plot of reported filtration efficiencies formerly determined by heating and ventilation standards (see Figure 1). Retention efficiencies were plotted for each particle channel size on the laser particle counter (0.3 to 0.5 µm, 0.5 to 5.0 µm, > 5.0 µm) as the center of that corresponding channel size when possible (0.4 µm, 2.75 µm, and 5.0 µm, respectively). Slight disparities in retention efficiency between the 2 test methods at similar particle sizes arose from differences in both the type of challenge particulate used and particle size classification methods. As such, the detection of only marginal differences in filtration efficiency at similar particle sizes between the 2 test methods suggests that the intake filters were performing within specification in their environment of use.

Airborne Contamination Emissions in the Operating Theater. Twenty-three FAW blowers (Bair Hugger 750) were sampled in their dedicated operating theaters. The distribution of ambient air quality provided by the ventilation system in the operating theater was relatively uniform. Particle counts ranged from 150 to 39,000 particles greater than 0.3 µm/cu ft centered on a median of 4,400 particles greater than 0.3 µm/cu ft; upper and lower quartiles were, respectively, 7,000 and 1,800 particles greater than 0.3 µm/cu ft.

Distal hose end air stream particle emissions were well above what would be expected for most FAW blowers (n = 22) based on intake filter performance (Figure 2); 96% of FAW blowers were generating significant levels of contamination greater than 0.3 µm in size. These FAW blowers were generating up to 110,000 particles per cubic foot downstream of the intake filter, which at an airflow of 1,274 L/min (45 cu ft/min) translates to 82,500 particles per second being emitted from the FAW blower hose end. Moreover, 70% of the FAW blowers had hose-end airflows with higher contamination levels than in intake airflows.

Internal Air Path Microbial Colonization. Air path swabs revealed the presence of viable microorganisms in 100% of FAW blowers (Table), with the heaviest growth reported on the internal air path surfaces of the elbow (Figure 3). Isolates of coagulase-negative *staphylococci* (CoNS), mold, and *micrococci* were detected inside 74%, 26%, and 9% of FAW blowers, respectively. Pearson correlation coefficients indicated a general lack of correlation between blower-generated particles and internal levels of microbial colonization for the combined CFU measure (P = .23) and individual swab locations. Microbes were detected on a high percentage of the control samples in nonspecific growth medium control samples (50%). However, the degree of colonization in the controls was much less than in sampled FAW devices, approximately 2% (see Figure 3).

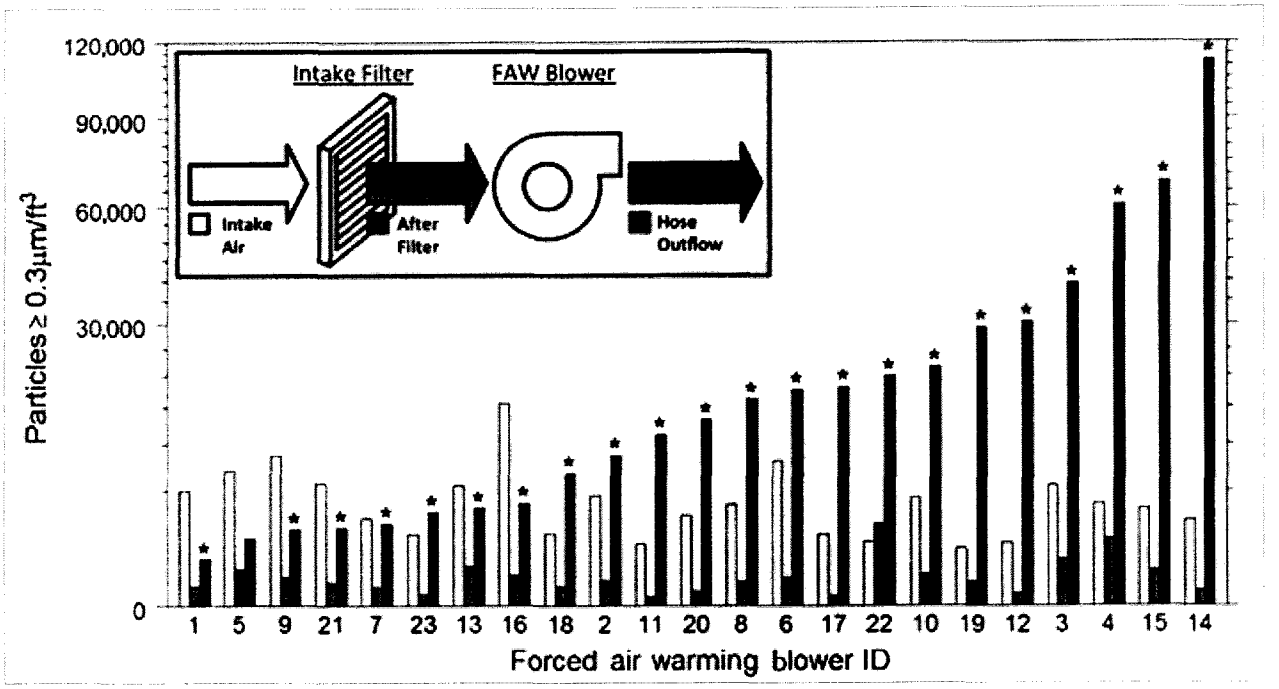

Figure 2. Airborne Particle Concentrations of Intake Air, After Filter, and Hose Outflow[a]
Abbreviations: FAW, forced-air warming; ID, identification number.
[a] 0.3 µm/cu ft = .
* Indicates significant elevations ($P < .05$) in hose-outflow particle concentrations vs after-filter particle concentrations.

Discussion

The results of this study suggest that inadequate FAW device intake filtration (63.8% efficient) led to a significant buildup of internal microbial contamination in the FAW blowers sampled. This buildup occurred on inaccessible air path surfaces that could not be cleaned. Most FAW blowers were also found to be internally generating airborne contamination downstream of the intake filter. This contamination was emitted into the operating theatre through the FAW hose-end airflow.

Similar research was undertaken in the United States on legacy FAW devices (Bair Hugger 505) having a substantially higher intake filtration efficiency (93.8%).[3] The reduced filtration efficiency (63.8% efficient) exhibited by current-generation FAW devices in the present study appeared to result in substantially higher levels of internal air path colonization and airborne contamination emissions. Furthermore, the composition of identified microbes in current-generation FAW blowers favored pathogens associated with surgical site infection (76% detection rate for CoNS), whereas the detection rate for such pathogens was less in legacy FAW blowers (17% combined detection rate for S *aureus*, CoNS, and MRSA). Differences in surgical practices and environmental factors between US and European hospitals may have contributed to this observed discrepancy. However, it is difficult to overlook the observed reduction in intake filtration efficiency as the primary factor responsible for greater internal colonization and emissions.

Microorganism detection by internal air path location, % of FAW blowers	
Distal hose end	96
Elbow	95
Combined (either location)	100
Specific organism detection, % of FAW blowers	
Staphylococcus aureus	0
Coagulase-negative *S aureus*	74
Methicillin-resistant *S aureus*	0
Mold	26
Micrococci	9
Pearson correlation of FAW contamination generation and CFUs by site, coefficient (*P* value[a])	
Distal hose end	0.19 ($P = .39$)
Elbow	0.25 ($P = .26$)
Combined (either location)	0.26 ($P = .23$)

Table. Detection of Microorganisms and Pearson Correlations Between Forced-Air Warming (FAW) Blower–Generated Particles and Colony-Forming Units (CFU) by Swab Location
[a] *P* values represent the probability that there is no linear correlation.

Many, perhaps most, physicians assume that a "0.2 µm–rated" intake filter removes all particles greater than

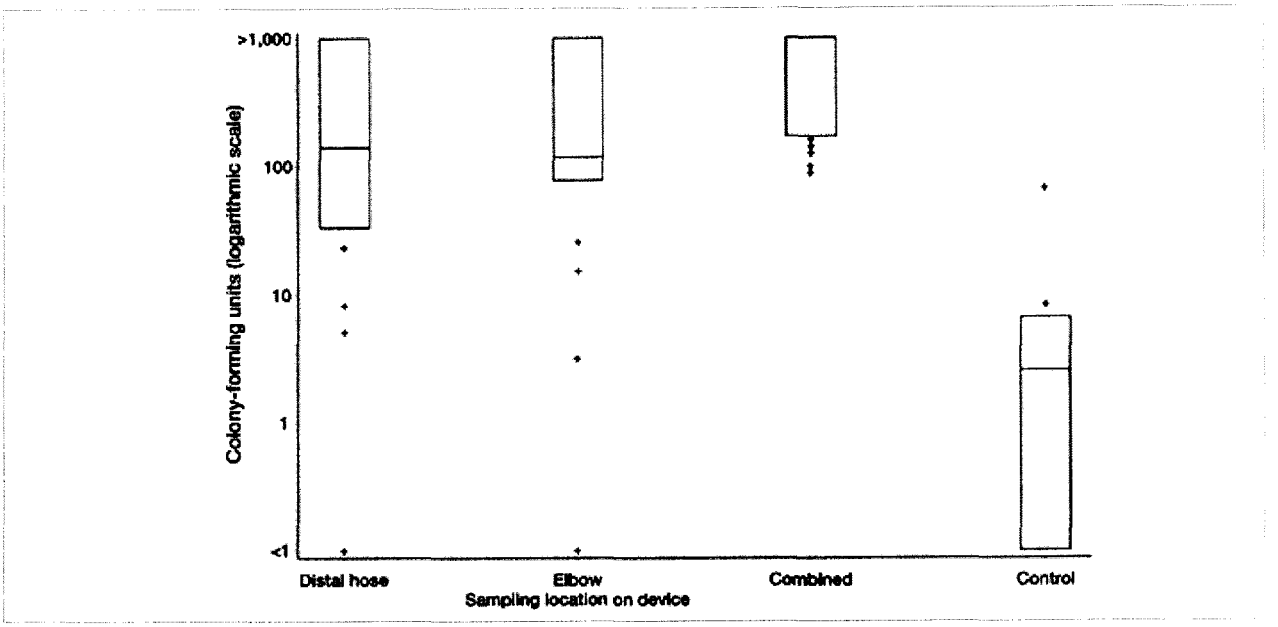

Figure 3. Detected Colony-Forming Units by Forced-Air Warming Device Sampling Location and Control Samples, Reported as 25th, 50th, and 75th Percentiles With Marked Outliers

0.2 µm using a straining action with pore sizes equal to 0.2 µm. For example, the discussion from one of the more commonly cited references on this subject matter states: "the floor mounted blower used in the present study is designed with a 0.2-µm filter at the air intake, this size being much smaller than the average size of bacteria-carrying particles (20 µm)."[4] In fact, the "0.2-µm" rating means quite the opposite and instead specifies the particle size that most easily penetrates the intake filter (see Figure 1). Depth filters, such as those used by FAW devices, are not constructed to have a defined pore size, but instead are a matted layer of fibers. The mechanisms of filtration are much more complicated than a simple straining action and principally rely on a particle's random motion intersecting a fiber within the filter.[5] Thus, the use of a 63.8% efficient, 0.2 µm–rated intake filter does not prevent the passage of contaminants greater than 0.2 µm through the filter and into the FAW blower. Instead, contaminant penetration is dependent on filtration efficiency at a given particle size, where filtration efficiency tends to be higher for particles larger than the 0.2 µm MPPS. This dependency explains why the intake filters were shown to be 87% and 89% efficient for particles 0.3 to 0.5 µm and 0.5 to 5.0 µm in size, respectively. Yet, this level of intake filtration implies that approximately 10% of the larger ambient airborne contaminants pass through the intake filter and into the FAW blower.

As such, the nature of the internal contaminants is likely to depend on both the past and present usage environments. The typical location for FAW blowers in the operating theater tends to be near the floor by the head of the operating table. Movements of the surgical staff and patient have been shown to generate large quantities of desquamated skin cells, of which as many as 10% have been shown to carry viable microorganisms.[6] Studies have shown these shed skin cells to have a wide particle size distribution extending below 5 µm because of flake fragmentation.[7] These skin cells are affected by gravity and the downward nature of the laminar airflow, both of which direct them toward the floor and the FAW blower intake. The reduced efficiency of the intake filter suggests that these pathogen-carrying cells penetrate the filter and buildup on the FAW blower's internal air path surfaces. This mechanism of airborne skin cell "seeding" is a likely explanation for the high degree of internal colonization, which is supported by the findings that 74% of reported isolates were skin-specific organisms (CoNS). Furthermore, the swabbing results of other studies[3,8-11] have found microbial contamination on internal air path surfaces consisting of skin isolates associated with surgical site infection (*S aureus*, CoNS, MRSA).[2]

As a whole, these findings question an important and common assumption about the design of FAW devices, namely that "all forced-air warming [blowers] include filters that essentially eliminate bacteria in the heated air."[12] Supporting evidence for such a statement was based on evaluations of overall operating theater contamination with instruments such as settle plates.[4,13,14] Only recently has the performance of FAW intake filters been directly studied.[3] However, for a direct risk to be present, the exhausted FAW airflow would need to reach the surgical site. It is presently unknown whether this happens, because surgical drapes may act as a barrier. Moreover, the coverlet may act as a low-efficiency microbial filter.[9]

Both of these issues warrant additional research.

This study has several limitations. First, we were unable to locate service/maintenance records indicating that the intake filters were regularly replaced. However, we did not detect any major degradation in filtration performance for 22 of the 23 intake filters that were individually tested in the operating theater (see Figure 2). Furthermore, depth filtration media tend to offer improved filtration as they load up[5]; thus, the concern that the filters were performing under specification appears to be minimal. Second, we did not sample for microorganisms in the hose-end airflow and instead relied on particle counting to quantify airborne contamination emissions. Our assessments of clinical risk assume that a portion of the emitted contaminants are microbial in nature, an assumption that is supported by prior research.[9] Last, we did not track hospital infections, nor did we study the association between FAW contamination generation/emission and hospital infection rates; the aims of this study were limited to evaluating the design of FAW equipment in regard to prevention of contamination buildup and emissions.

To address the identified design deficiencies, manufacturers should redesign FAW blowers to allow for regular cleaning and decontamination in accordance with governmental guidelines for reusable medical equipment.[15-17] Second, inlet filtration could be upgraded to HEPA quality (99.97% efficient) to prevent microbial ingress. Last, the addition of a filter at the distal hose end would be of benefit in reducing airborne contamination emissions. Outside these suggested design changes, the perioperative surgical care team should be aware of the apparent cross-contamination risks of moving FAW equipment between clean and dirty environments. Presumably, FAW equipment used during clean surgery should be confined to its dedicated operating theater of use.

REFERENCES

1. Radauceanu DS, Dragnea D, Craig J. NICE guidelines for inadvertent peri-operative hypothermia. *Anaesthesia*. 2009;64(12):1381-1382.
2. Mangram AJ. Guideline for Prevention of Surgical Site Infection, 1999. Centers for Disease Control and Prevention (CDC) Hospital Infection Control Practices Advisory Committee. *Am J Infect Control*. 1999;27(2):97-132.
3. Albrecht M, Gauthier RL, Belani K, Litchy M, Leaper D. Forced-air warming blowers: an evaluation of filtration adequacy and airborne contamination emissions in the operating room [published online November 20, 2010]. *Am J Infect Control*. 2011;39(4):321-328.
4. Zink RS, Iaizzo PA. Convective warming therapy does not increase the risk of wound contamination in the operating room. *Anesth Analg*. 1993 Jan;76(1):50-53.
5. Stephen B. *NAFA Guide to Air Filtration*. 3rd ed. Virginia Beach, VA: National Air Filtration Association; 2001.
6. Noble WC, Davies RR. Studies on the dispersal of staphylococci. *J Clin Pathol*. 1965;18:16-19.
7. Mackintosh CA, Lidwell OM, Towers AG, Marples RR. The dimensions of skin fragments dispersed into the air during activity. *J Hyg London*. 1978;81(3):471-479.
8. Albrecht M, Gauthier R, Leaper D. Forced-air warming: a source of airborne contamination in the operating room? *Orthop Rev Pavia*. 2009;1(2):e28.
9. Avidan MS, Jones N, Ing R, Khoosal M, Lundgren C, Morrell DF. Convection warmers – not just hot air. *Anaesthesia*. 1997;52(11):1073-1076.
10. Bernards AT, Harinck HI, Dijkshoorn L, van der Reijden TJ, van den Broek PJ. Persistent Acinetobacter baumannii? Look inside your medical equipment. *Infect Control Hosp Epidemiol*. 2004;25(11):1002-1004.
11. Baker N, King D, Smith EG. Infection control hazards of intraoperative forced air warming. J Hosp Infect. 2002;51(2):153-154.
12. Sessler DI. Complications and treatment of mild hypothermia. *Anesthesiology*. 2001;95(2):531-543.
13. Huang JKC, Shah EF, Vinodkumar N, Hegarty MA, Greatorex RA. The Bair Hugger patient warming system in prolonged vascular surgery: an infection risk? *Crit Care*. 2003;7(3):R13-R16.
14. Tumia N, Ashcroft GP. Convection warmers--a possible source of contamination in laminar airflow operating theatres? *J Hosp Infect*. 2002;52(3):171-174.
15. TIR12-2010: Designing, testing, and labeling reusable medical devices for reprocessing in health care facilities: a guide for device manufacturers. Arlington, VA: Association for the Advancement of Medical Instrumentation; 2004.
16. Government of Canada, Health Canada. *Draft Guidance Document: Information to be Provided by Manufacturers for the Reprocessing and Sterilization of Reusable Medical Devices*. Ottawa, Ontario, Canada: Minister of Health; June 11, 2006.
17. Directive C. 93/42/EEC of 14 June 1993 concerning medical devices. *Off J Eur Communities*. 1993;169:1-43.

AUTHORS

Mike Reed, MBBS, MD, FRCS, is a consultant orthopaedic surgeon at Northumbria Healthcare NHS Trust, United Kingdom.

Oliver Kimberger, MD, is an anaesthesiologist at Medical University of Vienna, Austria.

Paul D. McGovern, BSc, MBBS, MRCS, PGCME, FHEA, is specialty registrar in trauma and orthopaedics at Medway Maritime Hospital, Kent, United Kingdom.

Mark C. Albrecht, MStat, MBA, BSME, is clinical research manager at Augustine Temperature Management in Eden Prairie, Minnesota, United States.